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METEOROLOGICAL INSTRUMENTATION SUPPORT FOR AN ADVERSE WEATHER TEST FACILITY

Michael J. Burke

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13. ABSTRACT *(Maximum 200 words)*

This report defines the various basic meteorological instruments to be utilized in support of an all weather performance reliability testing facility for smart munition's millimeter wave/infrared sensors. The instrumentations discussed will measure the following environmental conditions: wind direction and speed, temperature, barometric pressure, humidity, rain rate, and solar radiance.

14. SUBJECT TERMS

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INTRODUCTION

The purpose of this report is to define the various basic meteorological instruments to be used in a sensor/seeker performance reliability testing facility called an Adverse Weather Test Facility (AWTF). A testing center of this type has been designed at ARDEC in order to better support smart Weapon sensor development. This facility was initially funded by the SADARM program, and has been designed to test all types of smart munition sensors in adverse weather.

Atmospheric weather conditions such as rain, snow, fog, temperature, wind, etc. have proven to degrade the performance of sensor/seekers in smart weapon systems. In order to better validate the design of a sensor, performance testing in adverse weather should be added to existing sensor tests. This testing should be conducted in an area likely to experience all forms of weather that could possibly occur within the scope of armed combat. It is important that the results of this testing not only include sensor target detection capability, but also include environmental conditions that were occurring during the test. This will enable evaluation teams to directly correlate sensor performance to the weather.

Proper acquisition of adverse weather data will also contribute to another aspect of sensor development, simulation modeling. A valid simulation model of a sensor would greatly assist developmental testing in terms of time and money. When simulating a sensor, all possible degrading elements that are applicable to the test scenario such as countermeasures, and adverse weather conditions should be accessible for insertion. A computer simulation may be validated by setting the simulation parameters up to match an existing sensor test.

Due to the importance of recording environmental conditions during sensor testing and the costs associated with quality meteorological instrumentation, it is important that various forms of environmental parameters measured be relevant to the sensor performance, and that the frequency of data collection of each parameter be recorded in a proficient and analytic manner.

METEOROLOGICAL INSTRUMENTATION

With regard to testing a sensor in adverse weather, the ability for the sensor to detect a target is dependent upon the environmental conditions occurring during the sensor test. This will validate environmental requirements established in the sensor's statement of work. Due to the many environmental conditions that can affect sensor performance, a complete complement of the conditions must be recorded. Of the many combinations of weather conditions, the main purpose of the facility is to record the weather parameters that are known to affect millimeter wave/infrared (MMW/IR) sensor performance.

Even though there are many types of meteorological instruments, the techniques for making measurements are for the most part very similar. The common meteorological measurements made in an AWTF; wind speed and direction, temperature, pressure, humidity, rain rate, and solar radiance, will be presented in the next section.

Wind Direction and Speed Measurement

These two parameters affect radio frequency (RF) clutter characteristics, IR target-to-background contrasts, and overall IR clutter. Wind direction is measured in units of degrees of the compass, such as 90 degrees, which means that the wind is coming from the east. Wind speed is measured in units of distance per time, such as 10 miles per hour.

Wind direction can be measured by attaching a single wind vane to a sensitive potentiometer. As the wind changes direction, the vane will rotate until it reaches the least resistance to the path of the wind directly in line with it. When a voltage is applied to this sensor, the resulting current can be fed into a calibrated meter to convert the analog signal into degrees of the compass. A drawing of a typical wind directional sensor is depicted in figure 1.

This parameter should not be recorded continuously since it would take up too much data space on the recorder. The best data recording frequency would be to continuously record during an actual sensor test. Throughout other longer times, perhaps one sample every few minutes will do. Calibration of the wind direction instrument is accomplished by adjusting the direction of the vane so that it is in line with a compass's orientation. The operator can then manually move the wind vane to a known compass direction and check the output of the instrument for accuracy.

Wind speed can be measured by using an anemometer (fig. 2). This instrument is comprised of a contact switch attached to a series of wind vanes. Unlike the wind direction sensor, this instrument is comprised of several vanes located around its central axis. This will allow for consistent rotation of the apparatus by wind from any direction. The rotation of the wind vanes will cause a series of openings and closings (pulses) of a contact switch. The unit is then calibrated so that the number of times the switch opens and closes is related to the distance traveled by the vanes. The number of pulses recorded within a known time period can provide the speed of the wind. This instrument can be calibrated by attaching a fixed speed motor to the wind vane's axis, then comparing the output of the sensor to the known motor speed.

Temperature Measurement

Temperature can affect passive RF and IR target-to-background contrasts, readings from an IR transmissometer and overall IR clutter. Temperature is measured in units of degrees and has three main scales of measurement, Fahrenheit, Centigrade, and Kelvin. The Kelvin scale is used in the field of thermodynamics. Meteorological measurements are normally recorded in either Fahrenheit or Centigrade. These two scales are based relative to the triple point of water, which is the region of state changes of water between solid, liquid, and gas, 32°F or 0°C for the change from solid to liquid and 212°F or 100°C for the change between liquid and vapor. There are many methods for measuring temperature; however, only the temperature measurement methods most generally used in the meteorological field will be discussed.

The most common method used to measure temperature is the liquid-in-glass thermometer (fig. 3). This type of thermometer consists of a thin walled glass bulb attached to a stem with a sealed top. The bulb of the tube is usually filled with mercury. The ambient temperature surrounding the thermometer will cause the mercury to either expand, which will force the level of mercury in the stem to rise, or contract, which will cause the level of mercury to fall. The stem is marked on the outside with the temperature scale.

This method is best suited for visible data collection although automatic data collection devices may be added. An example of a recording method could consist of a magnetic attachment to a vertical potentiometer that would reflect the rise and fall of the mercury levels accordingly. An electronic circuit could then be designed to relate the various resistance values of the potentiometer to the temperature scale on the thermometer. The attraction between the magnet and mercury will cause a slower response, but temperature rarely changes suddenly. Another means for automated data collection with this type of temperature sensor is to use an optical sensor to detect the level of mercury in the stem. This would remove the physical interaction between the thermometer and recording device, but most optical sensors require a light transmitter, which could warm the mercury and thus raise the reading of the thermometer.

Another method for measuring temperature is to use a resistance thermometer probe as shown in figure 4. The theory behind this type of temperature measurement is that certain materials exhibit different resistance properties relative to the temperature of the material. When the material has properties which cause it to quickly respond to changes in temperature, it can be useful for measuring these changes. The resistance thermometer circuit consists of a precision resistor, a precision resistance measuring apparatus, and a relationship for relating resistance to the ambient temperature surrounding the resistor.

The precision resistors are typically made of platinum, nickel, copper, alumel, iron, or silver. The choice of material depends on the temperature range to be measured and the amount of money to be spent making the temperature measurement. Platinum resistance thermometers are the most expensive; however, they are widely used because of their linear resistance-to-temperature relationship, wide temperature sensing range, resistance to corrosion and oxidation, high melting point (1000°C), and ease of malleability into a desired shape, without degrading its level of purity. This type of sensor can be attached to a data recording system.

Another method for temperature measurement is the thermoelectric thermometer, or thermocouple. The thermocouple measures temperature using a phenomenon resultant when two different metals are joined together and the two attachment points are placed at different temperatures. An electromotive force (emf) in the form of an electric current is induced through the metals. Different combinations of metals give distinct resultant currents relative to the difference in temperatures between the two junctions. A thermocouple circuit (fig. 5) usually consists of one junction held at a constant temperature, such as 32°F in a container of ice water, and the other end held in the area to be measured.

Thermocouple circuits are often used in industry for high temperature measurement. The thermal emf characteristics of various other metals over a very wide range of temperatures when used in a thermocouple circuit with platinum are shown in figure 6 (ref 1). As shown in (b) [an enlargement of fig. 6(a)] this type of thermocouple circuit does not offer a very substantial voltage output for the temperature range that a meteorological station would measure. The heating elements used as calibration equipment for IR sensors often require thermocouple measurement for control of their temperature regulation.

Barometric Pressure

Barometric pressure is the measurement of atmospheric pressure at a specific elevation. This parameter affects the readings from the IR transmissometer. It is also used extensively by weather forecasters as a means of predicting the weather by observing the change in barometric pressure over a period of time. This pressure is measured in units of force per unit area, though on the news, the weather forecaster often only announces the amount and direction of change in pressure since the last broadcast.

Barometric pressure can be transformed into an electric signal that can be recorded by using a sensitive diaphram with strain gages implanted into its walls, as shown in figure 7 (ref 2). As the atmospheric pressure increases, it creates a force on the diaphram which is transferred to the strain gage. The strain gages can be connected to a circuit that relates the strain gage's change to the barometric pressure.

Humidity Measurement

Humidity can be defined as the amount of water vapor in the air being sampled. It can affect RF attenuation, passive RF target-to-background contrasts, readings from an IR transmissometer, and overall IR clutter. This parameter can also affect electronic equipment not properly sealed against moisture. The amount of water vapor that can be present in a sample of air is dependent upon the temperature and also the purity of the air and atmospheric pressure.

There are actually two different terms associated with humidity, absolute and relative. The term absolute humidity refers to the exact amount of water vapor present at a given temperature and can be measured in units of parts per million. Relative humidity is the percentage of actual water vapor in the air relative to the maximum allowable amount of water vapor for that measurement. A reading of 50% humidity at 65°F doesn't mean that the air sample consists half of water vapor, it means that the air has reached its half saturation mark.

A common way to measure humidity is to use the wet-dry bulb or sling psychrometer method which involves two glass stem thermometers (fig. 8). One thermometer has its bulb covered with a thin piece of absorbent material soaked in a solution that evaporates quickly, such as alcohol. The wet bulb is swung around in the air in order to speed up the evaporation. The amount of water vapor in the air (humidity) controls the amount and rate of the evaporation of the solution in the air. As the liquid evaporates, energy is drawn out from the wet bulb, and the thermometer will show a drop in temperature. The relative humidity can then be found by using a wet-dry bulb chart (fig. 9, ref 3) which relates the reduced temperature of the cooled wet bulb and the temperature of the dry bulb, ambient air, to the relative humidity of the air. The wet-dry bulb method is read visually, and is not appropriate for an automated weather measurement station.

There are several ways in which humidity can be measured electronically so that the readings can be integrated with an automated facility. One method is the chilled mirror method. This method uses an instrument which has a thermoelectrically cooled mirror in the path of a light source and a photosensor. As the mirror is cooled its surface will eventually become fogged up and disrupt the path of the light beam. This will occur when the temperature of the mirror reaches the temperature at which the current amount of water vapor in the air is at its maximum amount of saturation. This temperature is called the dewpoint. The relationship between the dewpoint and temperature can also give the relative humidity by using the graph shown in figure 10 (ref 4). A typical cooled mirror dewpoint sensor system can be seen in figure 11.

Another method of electronic relative humidity measurement is to allow the air to react with the properties of an electronic device such as a resistor or capacitor whose properties are sensitive to the amount of water vapor in the air. The thermal conductivity of air changes with the amount of water vapor. A capacitor's dielectric constant will vary with the conductance of the air between the charging plates. An enlarged illustration of an opened capacitor demonstrating the method is shown in figure 12.

A problem associated with this sensor is that by exposing the devices to air, they can easily become contaminated with pollutants in the air, which changes their calibrated value, rendering the unit useless as a humidity sensor. It does however allow the users of the weather station to evaluate the amount of contaminates in the air.

Rain Rate

Rain rate is a very important parameter to measure due to its ability to affect RF and IR clutter measurements, RF attenuation, RF and IR target-to-background contrasts, and also readings from the IR transmissometer.

Rain rate can be basically defined as the amount of water passing through a known volume of space in a known period of time. Unfortunately, it cannot be easily characterized. This form of precipitation can very greatly in the size of the drops as well as the number of drops in a known volume, and the speed at which the drops fall. Rain rate can be different at locations only inches apart, and can change instantaneously. Rain rate can be characterized as heavy or light rain but more descriptive definitions should also be added to further better explain, such as the total amount of rain to fall in a given time period, average rain drop size, etc. For most meteorological purposes, total amount of rain fall in a day is sufficient, but when using the rates of precipitation that may only occur for a few minutes as part of a sensor test, it is important to have continuous recording.

Rain rate measurement can be measured in several ways. The resultant accuracy of the measurements are related to the prices of the instruments used. The simplest method used to measure rain rate is called the tipping bucket (fig. 13). This method involves using a bucket set to tip over and empty itself as soon as the water inside reaches a certain level. Each time the bucket tips over and resets itself, a counter is advanced by one. The recorder then can give the total amount of water evacuated from the bucket in a known time period. This method is not ideal, in that it does not account for the rain falling during the reset period.

A more accurate method of measuring rain rate is to use an optical rain measuring instrument such as a light emitting diode weather identifier (LEDWI) (fig. 14). This instrument consists of an LED transmitter and receiver separated by a distance of about 30 inches. The instrument creates a beam of light in the transmitter pointed directly at the receiver. If there is any form of precipitation falling between the two, it will interfere with the beam and cause scintillation, or glittering of the light which is detected by the receiver along with the remainder of the beam unhindered by the precipitation.

An LEDWI can report if there is any form of precipitation at all, and if any, indicate what it is. It can also give an instantaneous rain rate and measure snow intensities. Typical rain and snow rate measurements are obtainable from 0.05 mm/hr to 1000 mm/hr.

Solar Radiance

Solar radiance is the measurement of radiation from the sun. It can be divided into a direct measurement of the sun's radiation, and a measurement of the sky irradiation of the energy from the sun. The radiation from the sun can affect the IR target-to-background contrasts and also the overall IR clutter.

For the direct measurement of the sun, an instrument called a pyrheliometer is used. This instrument measures the radiation emitted from the sun not filtered by the atmosphere that reaches the target area. The pyrheliometer measures the energy with a thermopile which is a group of thermocouples connected in series. The thermopile is situated on the bottom of a narrow tube pointed directly at the sun. The tube's purpose is to shield the thermopile from energy that is not directly from the sun. The thermopile absorbs the energy and converts it into an electric signal in units of spectral radiance per unit wavelength. It is important for this instrument to be mounted on a platform that has the ability to follow, or track the sun as it moves across the sky. The instrument must also be capable of turning itself on and off respectively, at dawn and dusk.

For the total solar radiance measurement, an instrument called a pyranometer is used. This operates like the pyrheliometer, but it is meant to record all of the radiance in the sky, such as the amount reflected by the sky and surrounding objects, not just that of the direct sun.

A pygeometer is also required to specifically measure the infrared radiation from the sun since the items to be tested at this facility may contain an IR sensor. Without this instrument, the sun's infrared energy can interfere with the sensor and the operator would not be able to tell if the sensor were operating correctly.

UTILIZATION OF THE METEOROLOGICAL INSTRUMENTATION

Equally important as the knowledge of what meteorological instrumentation is required for an AWTF, is the understanding of how to use it most effectively. This involves the placement of the instruments and the frequency of data collection from each instrument.

The site considered at Picatinny for the testing facility is a 120-foot-high drop tower. The sensor is to be suspended from a fixture designed to spin the sensor around, creating a search pattern on the ground. Calibration devices and a target are to be placed on the ground in the search path of the sensor. Meteorological measurements at the top of the tower near the sensor will include; wind speed and direction, temperature, pressure, humidity, and rain rate.

Measurements at the target would include all of the parameters being measured near the sensor with the addition of the three solar radiance measurement instruments. If the distance between the sensor and target is great, it may be wise to include a third weather station half way between the sensor and target. This additional station would consist of the same instruments found near the sensor; wind, temperature, pressure, humidity, and rain rate. The placement of this station and the station near the target, along with their interfaces to the data recording equipment, must be kept out of the search path of the sensor.

A study phase on the Adverse Weather Test Facility was completed by Georgia Tech Research Institute (fig. 15, ref 5). It shows a proposed view of the drop tower being used for testing a sensor similar to SADARM. There are two separate weather stations, one near the sensor and one near the target, a spin fixture holding a sensor, a scan pattern on the ground that includes a target and calibration devices, and a vehicle out of the scan pattern which will house the recording devices.

The data recording devices chosen for this facility must be capable of recording all measurements simultaneously. A time code signal must also be recorded in order to accurately correlate the measurements to any sensor testing. The frequency in which the meteorological parameters are recorded can be determined by the station operators need for data, and the amount of available media for data storage. During the facility's first year of operation, it may be desirable to have the meteorological measurements recorded on a continuous basis in order to define the weather characteristics of the area. During sensor tests, all measurements should be recorded frequently, once every few seconds. If the facility is to become automated, it will be important to ensure that the recording instruments do not run out of data storage space. All instruments must also be properly maintained, due to their exposure to the elements.

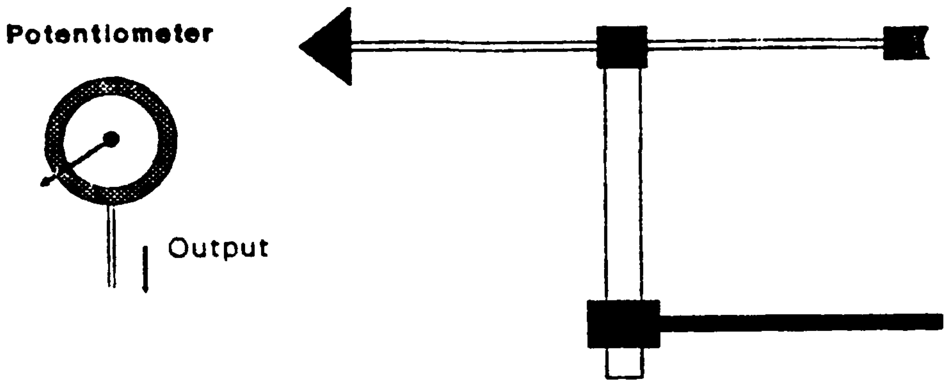


Figure 1. Wind directional sensor

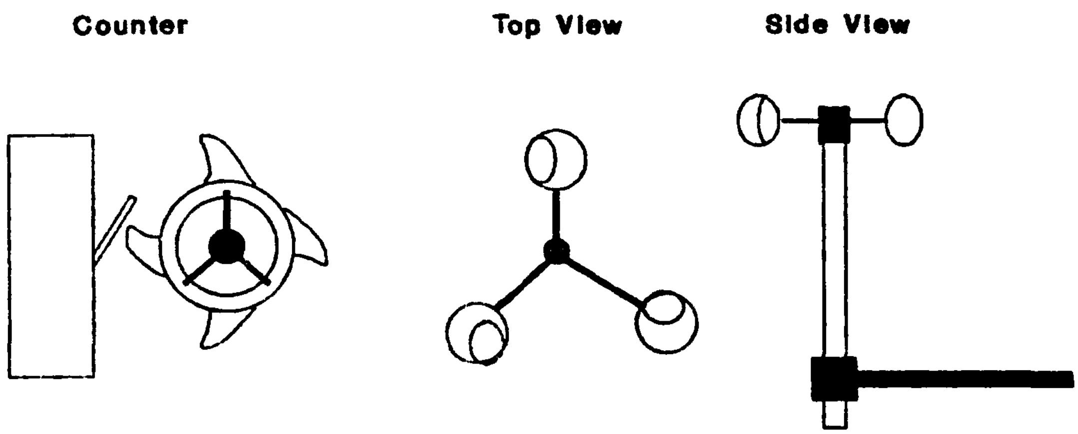


Figure 2. Wind speed sensor

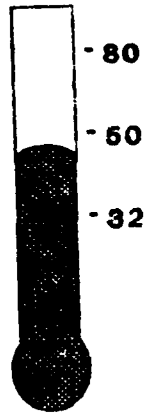


Figure 3. Common liquid in glass bulb thermometer

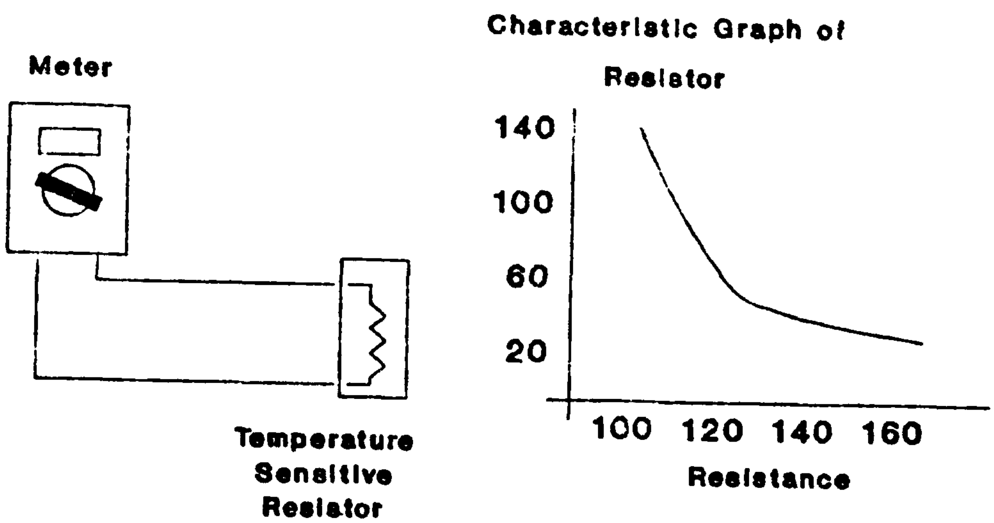


Figure 4. Resistance probe thermometer

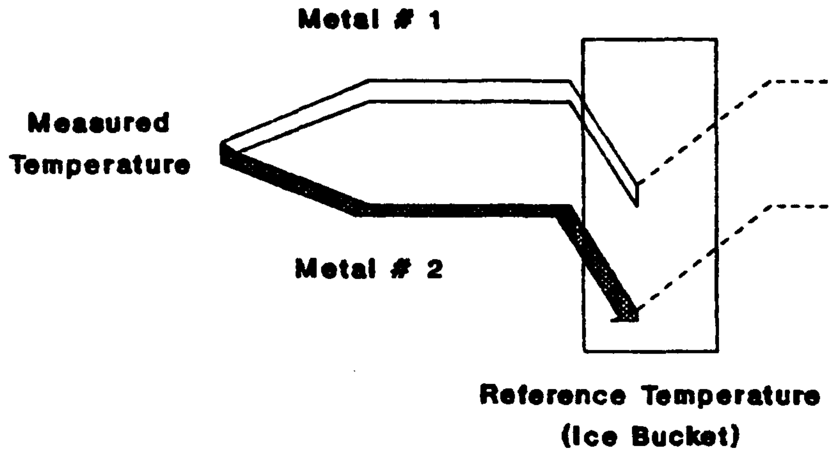
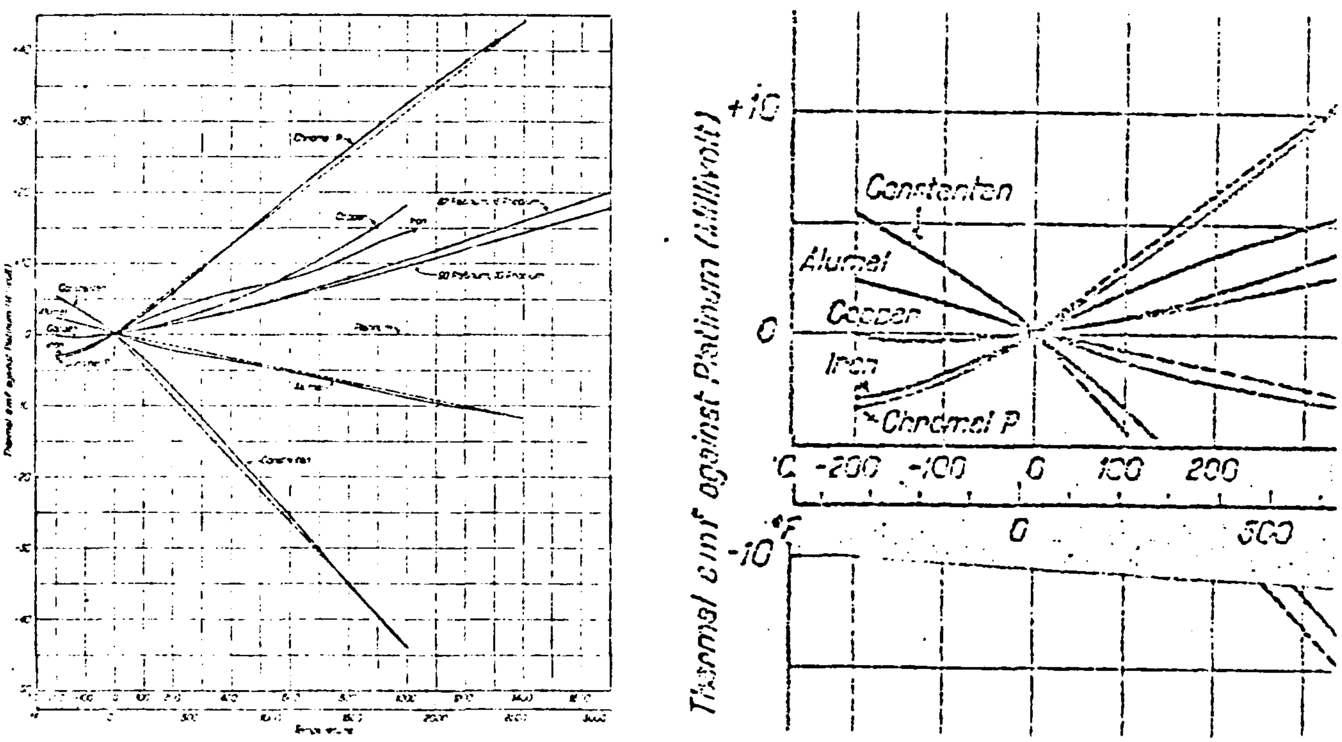


Figure 5. Thermocouple circuit

an enlargement of (a)



(a)

(b)

Figure 6. Platinum emf values

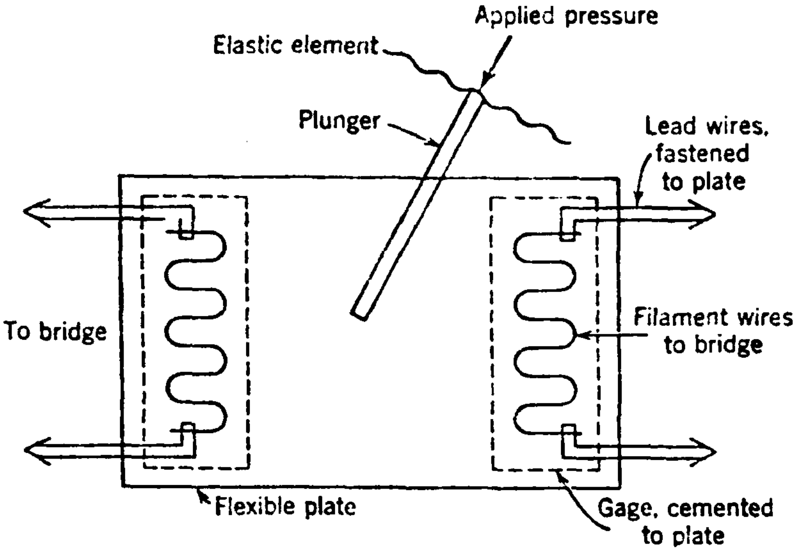


Figure 7. Bonded strain gage for barometric pressure sensor

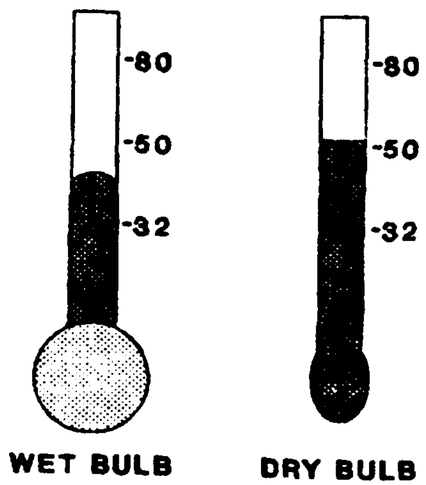


Figure 8. Sling psychrometer

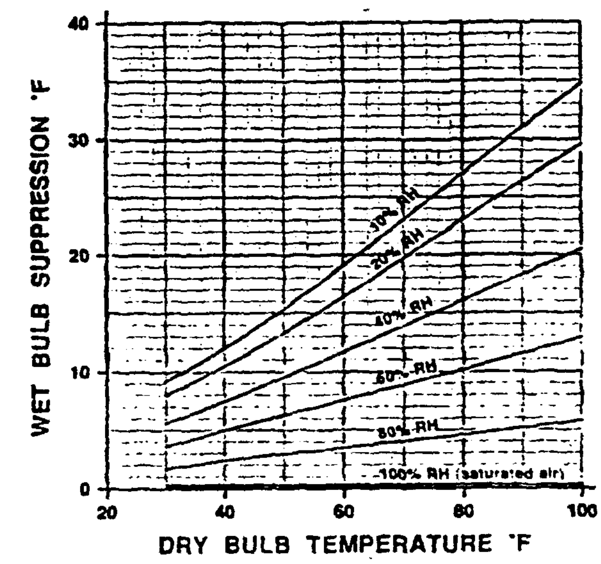


Figure 9. Relative humidity graph

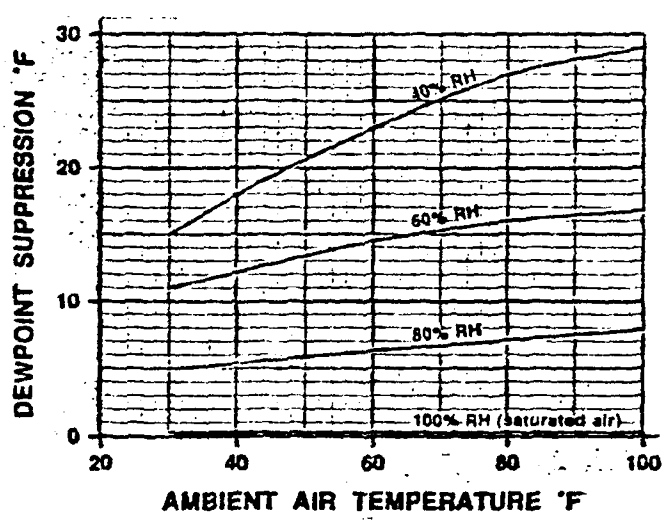


Figure 10. Relative humidity graph

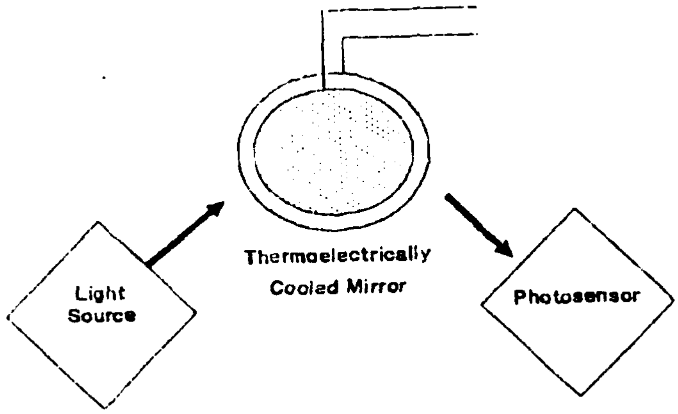


Figure 11. Cooled mirror dewpoint sensor

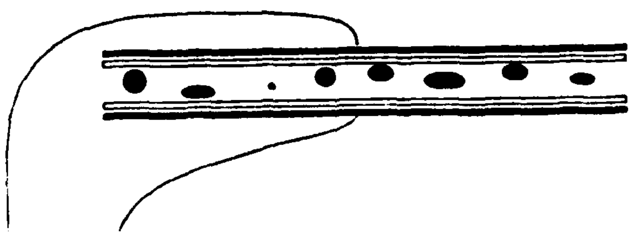


Figure 12. Capacitor humidity sensor

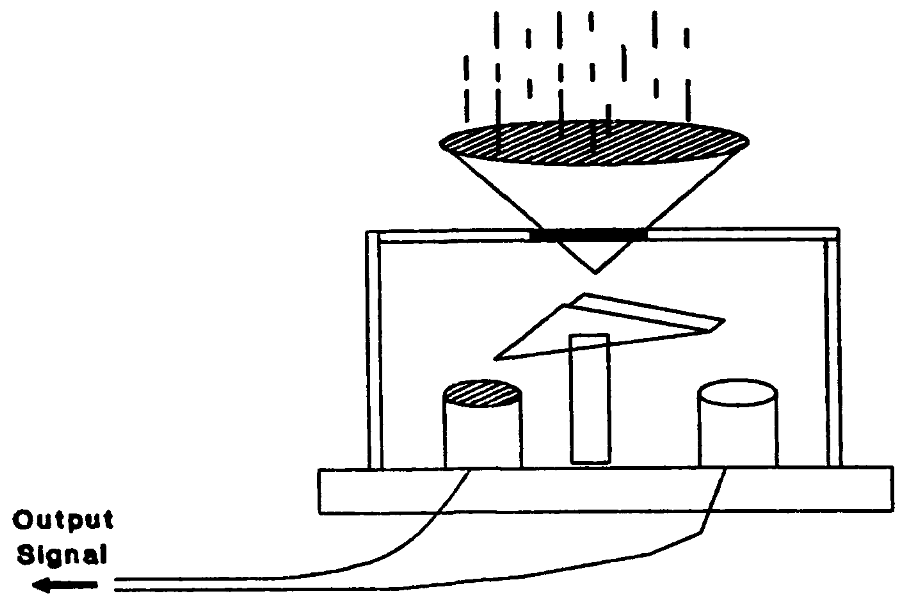


Figure 13. Tipping bucket rain rate sensor

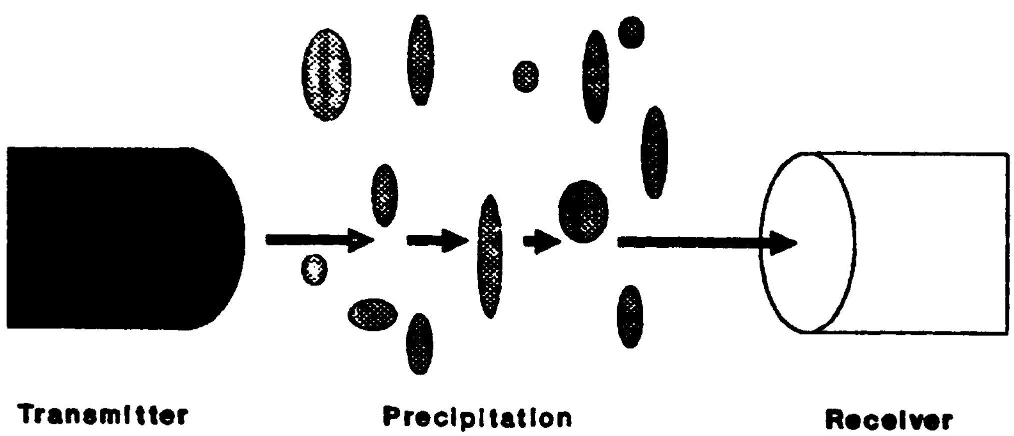


Figure 14. Optical weather identifier sensor

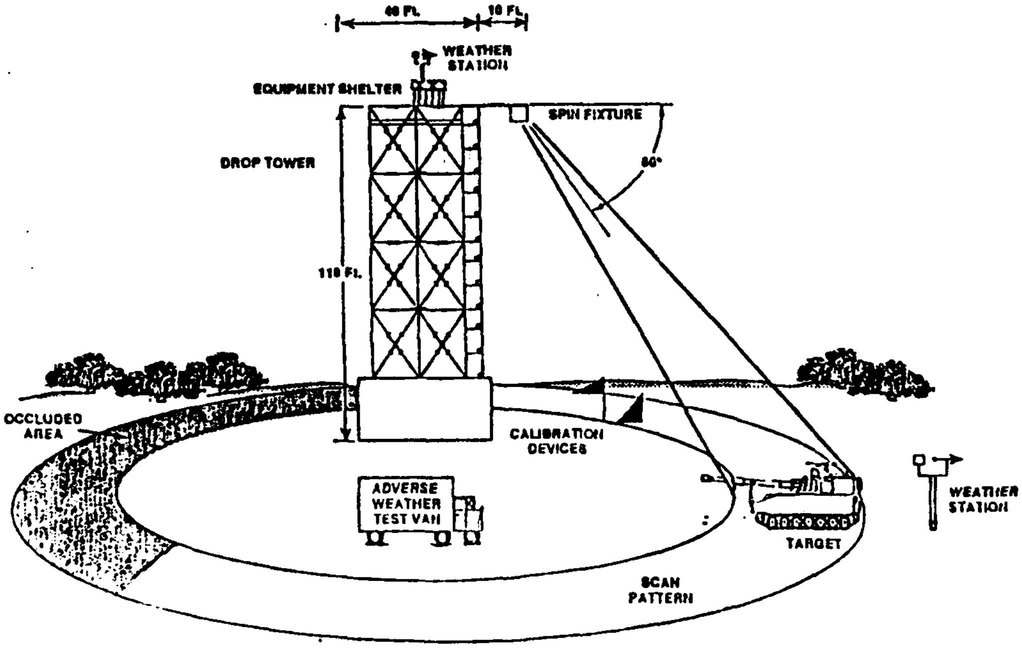


Figure 15. Proposed adverse weather test facility

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